Seasonal and diurnal changes of atmospheric boundary layer heights over Changwu, the Loess Plateau of China

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1. Introduction

Atmospheric Boundary Layer (ABL) height during daytime is the height of the mixed layer. ABL height is one of the important variables for the exchange processes of heat and water vapor between ABL and the free atmosphere. Thus ABL height is used as a fundamental variable for boundary layer studies.

Previous ABL observations have been mainly carried out under completely clear days. Previously proposed ABL height detection methods are assumed to be applied under this situation. However, most of humid environment, cumulus convection are often observed in midsummer season. We applied two ABL height detection methods over the Loess Plateau of China, and evaluated these methods under the condition of cumulus convection; one is the slab model and the other is the median filtering method. In addition, we also show seasonal and diurnal changes of ABL height over this region, in the summer of 2005.

2. Data and methodology

2.1. Data

The study site is located at the research field of Changwu Agro-Ecological Experimental Station on the Loess Plateau (35.24°N, 107.68°E, 1224 m A.S.L.). We analyzed vertical profiles of three-dimensional wind velocity and those of echo intensity measured by a Wind Profiler Radar (WPR, L-28, Sumitomo Electric Industries, Japan). We also determined surface heat fluxes and radiation fluxes using data obtained by Flux & Radiation Observation System (FROS, Climatec, Japan). Details of the study site and the instrumentation at the Changwu site were shown in Hiyama et al (2005).

2.2. Methodology

2.2.1. Slab model

The slab model is based on a one-dimensional energy conservation equation. The model [*Tennekes*, 1973; *Garratt*, 1992] is represented as

$$(Z_i+\Delta z)^2 = Z_i^2 + \frac{2(1+2\varepsilon)}{\gamma}\int_{t_1}^{t_2}(\overline{w'\theta_v'}) \qquad (1)$$

where Z_i is ABL height at $t = t_1$, Δz the increment of ABL height between t_1 and t_2, γ the moist adiabatic lapse rate 0.005 K m^{-1}, and ε the entrainment parameter. ABL height is estimated from time-integrated buoyancy flux $(\overline{w'\theta_v'})$ from t_1 to t_2, which is nearly equal to sensible heat flux. In this model, entrainment flux is taken into consideration, which is assumed to be proportional to surface buoyancy flux. Betts et al., (1992) suggested ε was as large as 0.4. However ε is variable between 0.1 and 0.3 depending on atmospheric conditions [*Yi et al.*, 2001]. In this study, following the previous studies, we assumed $\varepsilon = 0.2$ which has been regarded as a satisfactory value for dry ABL under clear days. We define ABL height estimated by the slab model as Z_{ical} in this study.

2.2. Median filtering method

We can determine diurnal change of ABL height using the vertical profiles of echo intensity observed by WPR. At the ABL top, peak (maximum) of the echo intensity is observed because refractive index fluctuations are the largest due to great changes of humidity and temperature. The median filtering method [*Angevine et al.*, 1994] is based on a firm foundation of theory and direct observations of echo intensity.

However, in partly cloudy days, erroneous ABL height was often detected due to the residual layer or stratiform clouds in the middle / upper troposphere [*Heo et al.*, 2003]. In this case, we judged ABL height erroneously from the time-height section of the echo intensity. Thus we recalculated ABL height lower than the erroneous ABL height by the median filtering method. We finally determined ABL height as Z_i in this study.

3. Results and discussion

Firstly, we selected "clear days" using radiation data. It was defined as the days when stratiform clouds did not cover in the lower / middle troposphere. Thus "clear days" included not only completely clear day but also the day when cumulus (Cu) developed. Totally 36 days were selected as "clear days" from 1 April to 31 July in 2005.

Figure 1 shows seasonal changes of sensible heat flux, latent heat flux and ABL height (Z_i). The daily maximum Z_i showed large day-to-day variation. Seasonal change of the daily maximum Z_i didn't correspond to those of the sensible heat flux. Next, we plotted daily maximum Z_i versus daily accumulated buoyancy flux in Figure 2. Some of Z_i were fluctuated and the difference between Z_i and Z_{ical} was quite large. On the other hand, some of Z_i agreed with Z_{ical} and the difference was small.

In order to explain the reason for this day-to-day variation, we investigated and classified diurnal changes of the ABL development in detail. We classified diurnal changes of ABL development into 2 cases. Case 1 is the day when difference between Z_i and Z_{ical} was small, and Case 2 is the day when difference was large. Figure 3 shows the diurnal changes of these ABL developments of Case 1 and Case 2. In Case 1, Z_{ical} showed good agreement with Z_i. On the other hand, Z_{ical} didn't agree with Z_i in Case 2. In this case Z_i suddenly developed and Z_i fluctuated largely in the afternoon. When Z_i suddenly developed in this case, strong updrafts and fair-weather cumulus were frequently observed. However, in Case 1, fair-weather cumulus were not observed.

In Case 1, Z_{ical} agreed with Z_i, thus both methods; median filtering method and slab model; detected ABL height successfully. However, in Case 2, when fair-weather cumulus developed, both methods failed to detect ABL height. In the median filtering method, the peak of the echo intensity appeared within fair-weather cumulus, then Z_i had large bias. In the slab model, Z_{ical} might be underestimated because the entrainment parameter is larger than 0.2 due to the strong mixing of cumulus convection.

4. Conclusions

We evaluated two ABL detection methods over the Loess Plateau China; one is the slab model and the other is the median filtering method. We focused only on clear days including fair-weather cumulus developments. When fair-weather cumulus weren't observed, Z_{ical} showed good agreement with Z_i. However, when fair-weather cumulus were observed, Z_{ical} didn't agree with Z_i. Therefore, ABL height detection under cumulus convective condition is difficult. We need to improve a ABL height detection method under cumulus convective condition.

References

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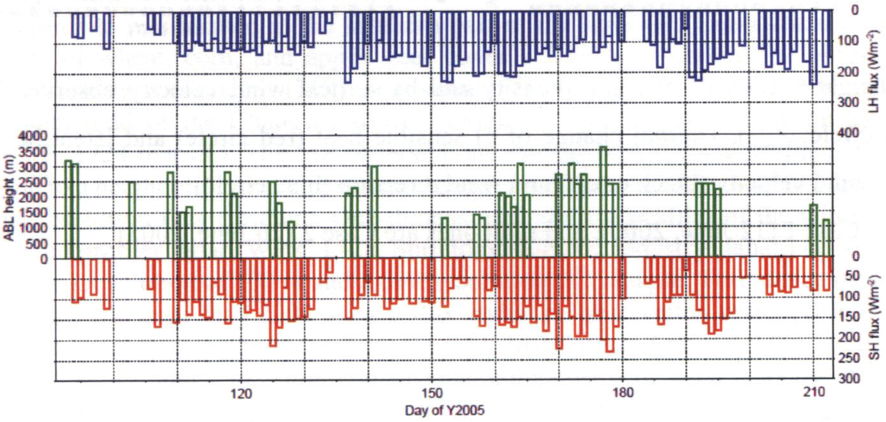


Figure 1 Seasonal change of daily mean latent heat flux (LH flux), daily maximum ABL height (Z_i, only "clear days") and daily mean sensible heat flux (SH flux) from 1 April to 31 July in 2005.

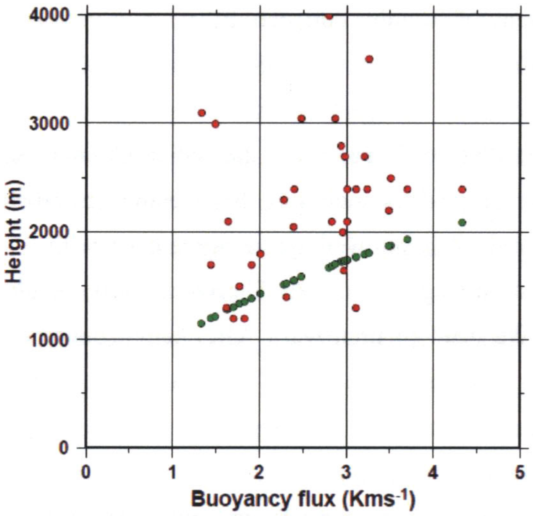
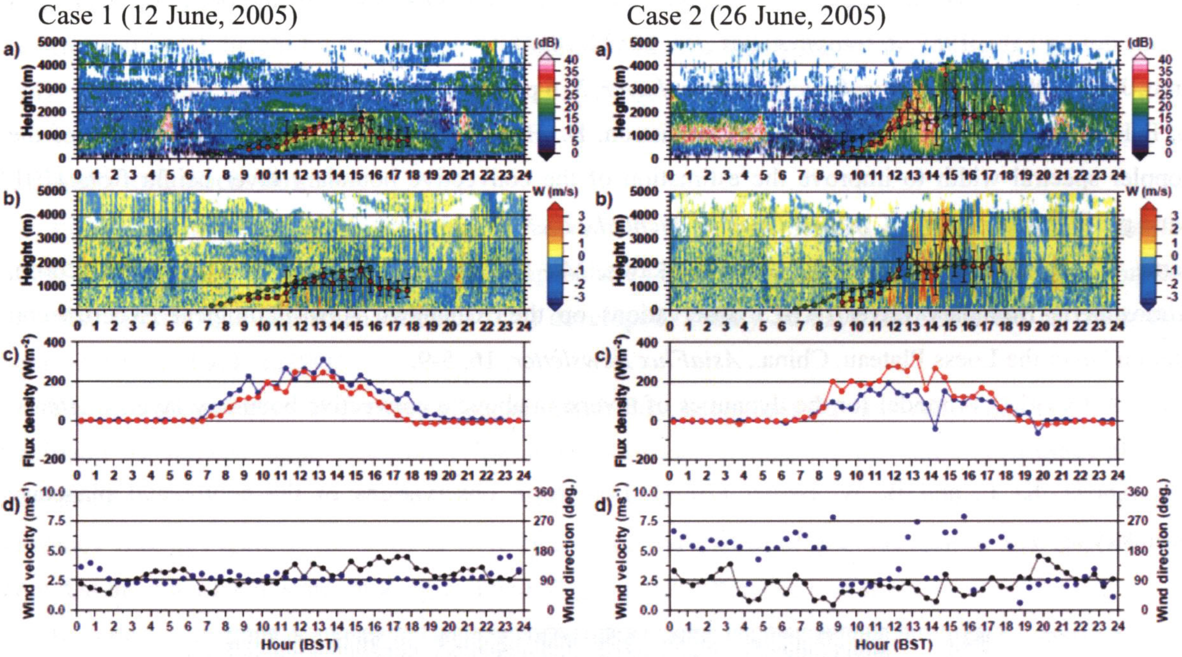


Figure 2 Daily maximum Z_i versus daily accumulated buoyancy flux from 1 April to 31 July in 2005. Red circles represent daily maximum Z_i and green ones represent Z_{ical} estimated from daily accumulated buoyancy flux using eq. (1).


Case 1 (12 June, 2005)

Case 2 (26 June, 2005)

Figure 3 Time-height section of a) echo intensity and b) vertical wind velocity observed by WPR (red circle: Z_i, green circle: Z_{ical}). Diurnal change of c) sensible heat (red circle) and latent heat fluxes (blue circle), that of d) wind velocity (black circle) and wind direction (blue circle).

Left figures show Case 1 (12 June, 2005), and right ones are Case 2 (26 June, 2005)